Preventing Terror in the Skies

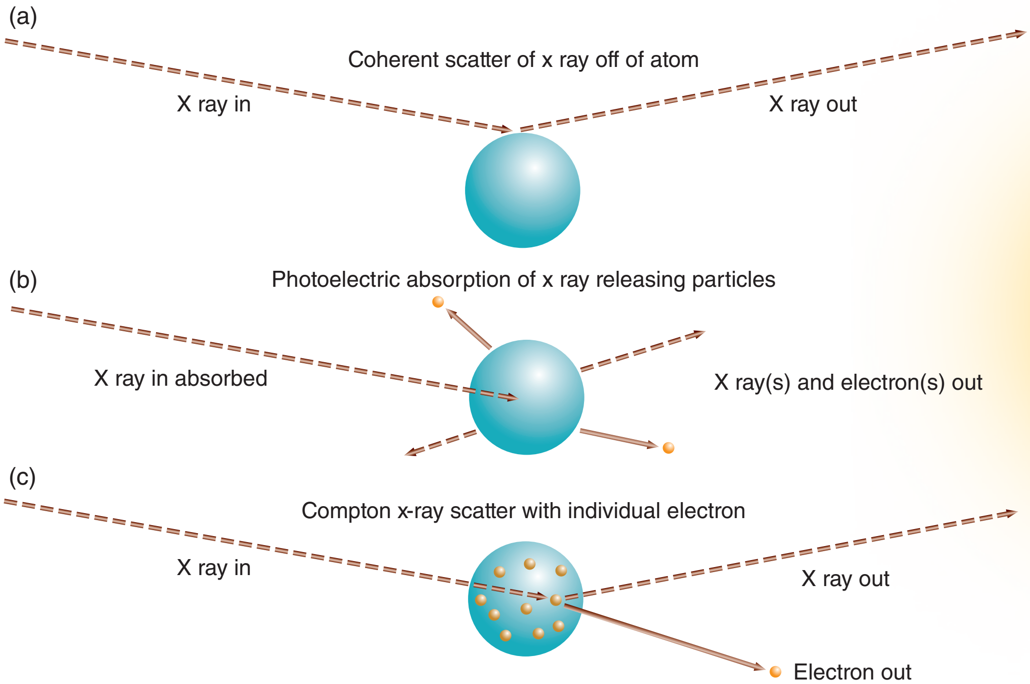
AIR travel is a popular mode of transportation. Each year, more than 600 million people board U.S. flights for business or pleasure. A coordinated terrorist strike on commercial airlines could have a detrimental effect on air travel and might cripple the nation's economy. The Transportation Security Administration has worked diligently to enhance security at airports and on flights so that people and cargo can continue to move freely.

Today, all passengers and every piece of checked or carry-on luggage are screened before they are permitted on an aircraft. X-ray systems and walk-through metal detectors allow security personnel to identify dangerous metal objects, such as guns and knives. Explosives detection technologies use x-ray computed tomography (CT) and other techniques to screen for explosives hidden in luggage and cargo destined for transport on passenger flights as well as on the people boarding the aircraft.

One challenge with scanning for explosives is that some nonthreatening materials share similar characteristics with actual threats, leading to false positives or false alarms. When an alarm is generated, security personnel must review the scan images to "clear" the alarm or manually verify the bag's contents, which can increase labor costs and lead to time delays.

To further improve aviation security, the Department of Homeland Security (DHS) Science and Technology Directorate is funding research to deploy advanced explosives detection technologies that can more accurately discriminate between a wide

Explosives detection technologies, such as these x-ray computed tomography machines, scan baggage to determine whether dangerous objects are hidden inside. (Courtesy of [left] Reveal Imaging and [right] Safran Morpho.)



At the energies used to scan luggage, three basic processes contribute to x-ray attenuation at the atomic level. X rays can be (a) deflected, (b) completely absorbed, or (c) partially transferred to an electron that is ejected from an atom in the object. The contribution that each process makes to the measured linear attenuation coefficient depends on the x-ray energy used and an object's density and elemental composition.

range of explosives and nonthreat materials. Toward this end, a team in Livermore's Engineering Directorate is evaluating the diagnostic performance of next-generation explosives detection technologies and providing recommendations to the Transportation Security Administration.

Materials Revealed

The Livermore project focuses on CT-based applications. First developed for the medical field as a method for diagnosing disease, x-ray CT has become instrumental in various industrial applications. Explosives detection equipment that incorporates CT uses a broad-spectrum x-ray beam to capture projections of an object, in particular, the objects inside a piece of luggage. CT applies complex reconstruction algorithms to the projections to produce a three-dimensional representation of the luggage and its contents. Automated threat-detection algorithms process the images to analyze the data and flag potential threats for further review. Transportation security officers can then examine these images and the relevant data to determine whether further interrogation is needed.

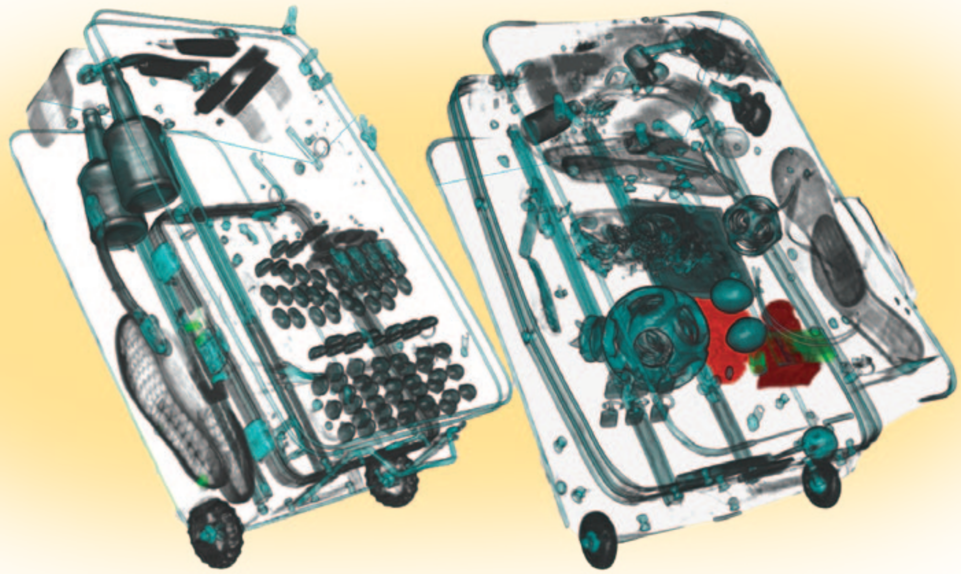
Harry Martz, who leads the Livermore explosives detection project, is an expert in CT systems, having spent more than 20 years working on CT technologies that support the Laboratory's national security missions. "Our objectives include creating a database of the x-ray properties of explosive threats and nonthreats, performing research and development on advanced CT algorithms to ensure that they produce precise reconstructions, and investigating new source and detector hardware to enhance the performance of existing or next-generation technologies," says Martz. "We are also exploring methods to further improve the performance of threat-detection algorithms as passenger loads continue to increase."

An Energetic Response

Images obtained from current CT-based explosives detection systems provide estimates of the linear attenuation coefficients and other features of the items inside luggage. "These attenuation coefficients depend strongly on a material's density and elemental composition and on the x-ray source and detector used to measure them," says Martz.

The Livermore scientists are evaluating reconstruction and automated threat-detection algorithms to determine how to improve these methods for use in advanced dual-energy techniques. In this detection scheme, the detector measures the linear attenuation coefficients of materials at two energy spectra, one low and the other high. The two measurements provide a stronger basis for interpreting an object's elemental composition and density, thus improving the system's detection capabilities with fewer false alarms.

At the energies used to scan luggage, x-ray attenuations are determined by three kinds of interaction processes occurring between the x rays and the object. In coherent scattering, incident x rays are deflected by atoms in an object, whereas in the photoelectric effect, they are completely absorbed. With Compton scattering, the x-ray energy is partially transferred to an electron that is then excited or ejected from an atom. "Current detection techniques combine the first two processes into a single parameter," says team member Jerel Smith. "By measuring



Computed tomography systems produce two- and three-dimensional digital images showing the contents of a bag. Transportation security personnel can review such an image to determine if a threat is present or to clear a false alarm. Areas highlighted in red indicate potential threats. (Courtesy of Safran Morpho.)

all three interactions, we may be able to obtain a more precise signature of the types of atoms within an object and thus more effectively identify specific explosive materials."

As part of the research effort, Smith and Livermore scientist Travis White are using the Laboratory's high-performance computers to model the three interaction processes. "With these models, we can artificially adjust the physics parameters, such as x-ray spectra, to improve our understanding of materials and object characterization," says White. With that knowledge, the researchers can evaluate the algorithms used in existing explosives detection systems and reconfigure the codes for enhanced performance.

Reconstruction algorithms process the projections from CT systems and correct for imperfections in the image quality. In some cases, artifacts, or errors introduced as part of the processing and reconstruction, compromise the image quality. Artifacts such as beam hardening, rings, and streaks can compound the problem. Improved reconstruction algorithms would reduce artifacts in CT images and enhance segmentation to more clearly define objects and their boundaries, increasing threat detection while decreasing the false-alarm rate and thus reducing the intervention required by security personnel.

Automated threat-detection algorithms analyze the CT images and extract relevant characteristics such as x-ray attenuation, density, effective atomic number, and mass of different materials in a scanned bag. The system then compares data generated by the algorithms with values of known explosives to classify each material as either a threat or a nonthreat. To improve the results produced in such comparisons, the Livermore team is redesigning the algorithms to better interpret the complex data, including multiple energy measurements. The researchers are also developing an expanded database of explosives properties to serve as a reference for the algorithms that process the CT data. The database will also be useful for other researchers working in this field, whether they are at other laboratories, government agencies, or academic institutions or with current or potential industrial partners. These improvements should allow explosives detection technologies to more accurately differentiate threats from nonthreats and thus enhance detection capabilities, reduce false-alarm rates, and increase the system's operational efficiency.

Lending a Hand

All explosives detection technologies must be certified by the DHS Transportation Security Laboratory before they are installed in airports. Ultimately, the research performed at Livermore and the resulting modifications to existing technologies will allow the DHS Science and Technology's Explosives Division, through the Transportation Security Administration, to deploy more efficient detection systems.

"We are advancing the technologies used at airports to screen for dangerous materials," says White. Thanks to Livermore's expertise in material characterization and high-performance computing, airport security personnel are becoming better equipped to stay one step ahead of the nation's adversaries, keeping airline passengers safer in an increasingly hostile world.

—Caryn Meissner

Key Words: automated threat-detection algorithm, aviation security, explosives detection, linear attenuation coefficient, Transportation Security Administration, x-ray computed tomography (CT).

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